A new absolute magnitude calibration with *2MASS* for cataclysmic variables

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Abstract

Using reliable trigonometric measurements, we find that the absolute magnitude of cataclysmic variables depends on the orbital period and de-reddened $(J-H)_0$ and $(H-K_s)_0$ colours of *2MASS* (Two Micron All Sky Survey) photometric system. The calibration equation covers the ranges $0.032^d < P_{orb} \leq 0.454^d$, $-0.08 < (J-H)_0 \leq 1.54$, $-0.03 < (H-K_s)_0 \leq 0.56$ and $2.0 < M_J < 11.7$; It is based on trigonometric parallaxes with relative errors of $(\sigma_\pi/\pi) \leq 0.4$. By using the period-luminosity-colours (PLCs) relation, we estimated the distances of cataclysmic variables with orbital periods and *2MASS* observations and compared them with distances found from other methods. We suggest that the PLCs relation can be a useful statistical tool to estimate the distances of cataclysmic variables.

Key words: 97.80.Gm stars: cataclysmic binaries, 97.10.Vm stars: distances, parallaxes

1 Introduction

Cataclysmic variables (hereafter referred to as CVs) are short period interacting binary stars in which a red-dwarf, the secondary star, overflows its Roche lobe and transfers matter to a white dwarf typically via an accretion disc. A bright spot is formed in the location where the matter stream impacts the accretion disc. In CVs that have strongly magnetic white dwarf pimaries the accreting matter can not construct an accretion disc, instead, the accretion is

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maintained through accretion columns above the magnetic poles of the white dwarf. For a detailed description of the CV phenomenon and its subclasses see Warner (1995) and Hellier (2001).

Although distances of CVs are needed to improve and constrain physical models, reliable distance measurements can be only found for a few systems. Different methods have been used to measure CV distances (Thorstensen 2003). However, all but trigonometric parallaxes yield rough distance estimates. The most promising method for determining CV distances has been to make use of the properties of the secondary star (Bailey 1981; Sproats, Howell & Mason 1996). This method assumes that all K-band emission originates from the secondary star. Almost all secondary stars in CVs lie on or near the ZAMS (Zero Age Main Sequence) for near-solar metallicity within the uncertainties (Warner, 1995; Beuermann et al., 1998; Beuermann, 2000; Kolb & Baraffe, 2000). However, if one tries to measure the absolute magnitude of the secondary star, contributions to the light from the other components contaminate the results. Therefore, only a lower limit to the distance can be obtained by using this method due to the effects of the disc and the irradiated area of the secondary star (Berriman, Szkody & Capps 1985). Almost all distance estimation methods attempts to use properties of a component of the system such as surface brightness of the secondary star (Bailey 1981), spectra of the white dwarf (Sion et al. 1995; Urban & Sion 2006) and $M_V - P_{orb}$ relationship of dwarf novae at outburst (Warner 1995; Harrison et al. 2004). However, none of them can give a distance as precise as trigonometric parallax due to the contaminations from the other components and the lack of the information about the individual contributions of the components to the observed light.

It is accepted that the most reliable distances are obtained from trigonometric parallaxes. However, this trigonometric parallax method can only be applied to the closest objects due to observational constraints. First precise trigonometric parallax measurements of the brightest CVs came from Hipparcos Satellite (Duerbeck 1999). Trigonometric parallaxes of some CVs were measured by using Hubble Space Telecope's Fine Guidence Sensor (McArthur et al. 1999, 2001; Beuermann et al. 2003a,b; Harrison et al. 2004), as well. In addition, Thorstensen (2003) measured trigonometric parallaxes of 14 CVs from ground-based observations.

A relationship of absolute magnitude in any wavelength interval with the orbital period and at least one colour of the system can be a very useful tool to estimate distances of binary stars. This method was applied for W UMa-type binary stars (Rucinski & Duerbeck 1997; Rucinski 2004). If there is such a relationship for CVs as well, their distances can be statistically estimated to a certain precision. For this, *2MASS* magnitudes and colours can be a good choice since most of the light in these photometric bands comes from the secondary star and the effect of the interstellar reddening for J, H and K

bands is weaker than that in visual wavelengths. Although we can not measure the absolute magnitude of the secondary star to a good precision, at least, we know that the secondary star in a CV can be considered as the least-active component of the system.

We should state that our aim is *not* to measure the absolute magnitudes of the secondary stars in CVs. In this study, we first estimate the systemic J-band absolute magnitudes M_J of the closest CVs using reliable trigonometric parallaxes by assuming that the light in J, H and K bands comes from the system as a *whole*. Then, we find the dependence of the absolute magnitude on the orbital period P_{orb} and de-reddened colours $(J-H)_0$ and $(H-K)_0$ to derive an absolute magnitude calibration for CVs with *2MASS* photometric system.

2 The Data

Our data sample consists of CVs with trigonometric parallax (π) errors smaller than $(\sigma_\pi/\pi)\leq 0.4$. The 27 systems listed in Table 1 include CVs with orbital periods shorter than $\sim$12 hr since a CV with orbital period longer than this limit possibly contains a secondary star on its way to becoming a red giant (Hellier 2001). Dwarf novae and nova-like systems were selected from Duerbeck (1999), McArthur et al. (1999, 2001), Beuermann et al. (2003a,b), Thorstensen (2003) and Harrison et al. (2004). Duerbeck (1999) obtained trigonometric parallaxes of four novae however, we included only two of them in our sample. The orbital period of T CrB (P_{orb} $\sim$228 days), which is classified as a recurrent nova in Downes et al. (2001) catalogue, is longer than our upper limit. In addition, a comparison of Tables 1 and 2 in Duerbeck (1999) shows that the distance of HR Del evaluated from the shell expansion parallax method is very different from its distance found from trigonometric parallax. Thus, we excluded these two systems from our sample. Table 1 lists the systems used in the analysis. Our data sample consists of 14 dwarf novae, 11 nova-like stars and two novae. These are CVs with the most precise distance estimates ever found in the literature.

J, H and K_s magnitudes were taken from the Point-Source Catalogue and Atlas (Cutri et al. 2003; Skrutskie et al. 2006) which is based on the *2MASS* (Two Micron All Sky Survey) observations. The *2MASS* photometric system comprises Johnson's J (1.25 μm) and H (1.65 μm) bands with the addition of K_s (2.17 μm) band, which is bluer than Johnson's K-band. Although we study the most closest CVs ever known, the total interstellar absorption in the direction of the star should be taken into account. We used the equations of Fiorucci & Munari (2003) for the determination of the total absorption for J, H and K_s bands, i.e. $A_J = 0.887 \times E(B-V)$, $A_H = 0.565 \times E(B-V)$

and $A_{K_s} = 0.382 \times E(B-V)$, respectively.

Fortunately, the $E(B-V)$ colour excesses of many CVs were estimated by Bruch & Engel (1994) and Harrison et al. (2004). Bruch & Engel's catalogue includes the systems whose $E(B-V)$ values were given in Verbunt (1987) and La Dous (1991). Our primary $E(B-V)$ source is Harrison et al. (2004). If we did not find the $E(B-V)$ value of a star in their study, we returned to Bruch & Engel (1994). Unfortunately, colour excesses of GP Com, GW Lib, EF Eri and V893 Sco were not given in the sources mentioned above. Thus, we calculated their colour excesses from Schlegel, Finkbeiner & Davis (1998) maps by using NASA Extragalactic Database [1]. Since these are relatively close systems, the colour excesses found from Schlegel et al. (1998) need to be reduced according to the stellar distance. In order to do this, we used the $E_\infty(B-V)$ colour excess in the Galactic latitude (b) and longitude (l) for the model from Schlegel et al. (1998). The total absorption for the model was evaluated from

$$A_\infty(b) = 3.1 E_\infty(B-V). \tag{1}$$

The total absorption for the distance d to the star is calculated as following (Bahcall & Soneira, 1980)

$$A_d(b) = A_\infty(b)\left[1 - exp\left(\frac{-\mid d\ sin(b)\mid}{H}\right)\right], \tag{2}$$

where H is the scaleheight for the interstellar dust which is adopted as 100 pc. Finally, the colour excess for a star at the distance d is estimated from

$$E_d(B-V) = A_d(b)\ /\ 3.1. \tag{3}$$

Once we obtained the apparent magnitudes (J, H and K_s), total absorption (A_J, A_H and A_{K_s}) and distance $d = 1/\pi$ for a CV, the absolute magnitudes (M_J, M_H and M_{K_s}) of the system were easily calculated from the well known distance-modulus formula, i.e. $M_J = J - 5\log d + 5 - A_J$. The calculated M_J values are listed in Table 1.

3 Analysis

We used the data in Table 1 to derive an absolute magnitude calibration for CVs with *2MASS*. In order to find the dependence of the absolute magnitude

[1] http://nedwww.ipac.caltech.edu/forms/calculator.html

Table 1

The data sample. Types and orbital periods (P_{orb}) were taken from Downes et al. (2001). DN, NL and N denote dwarf nova, nova-like star and nova, respectively. J, H and K_s magnitudes were collected from the *2MASS* Point Source Catalogue (Cutri et al., 2003). π denotes parallax, $E(B-V)$ colour excess and M_J absolute magnitude in J-band.

Name	Type	P_{orb} (days)	J	$J-H$	$H-K_s$	π (mas)	σ_π/π	$E(B-V)$	M_J
GP Com	NL	0.0323	15.72±0.07	0.10±0.15	0.48±0.21	14.8[f]	0.09	0.01[i]	11.55±0.26
GW Lib	DN	0.0533	16.19±0.09	0.60±0.15	0.19±0.22	11.5[f]	0.18	0.06[i]	11.44±0.48
EF Eri	NL	0.0563	17.21±0.24	1.54±0.28	0.30±0.22	5.5[f]	0.36	0.01[i]	10.90±1.03
WZ Sge	DN	0.0567	14.86±0.04	0.30±0.06	0.56±0.08	22.97[a]	0.01	0.00[a]	11.67±0.06
T Leo	DN	0.0588	14.77±0.04	0.44±0.07	0.51±0.08	10.2[f]	0.11	0.00[h]	9.82±0.28
VY Aqr	DN	0.0631	15.28±0.05	0.42±0.11	0.27±0.13	11.2[f]	0.12	0.07[h]	10.47±0.31
EX Hya	DN	0.0682	12.27±0.02	0.32±0.04	0.26±0.04	15.50[b]	0.02	0.00[a]	8.23±0.07
V893 Sco	DN	0.0760	13.22±0.03	0.31±0.04	0.23±0.04	7.4[f]	0.27	0.12[i]	7.46±0.61
SU UMa	DN	0.0764	11.78±0.02	0.05±0.03	0.06±0.03	7.4[f]	0.20	0.00[h]	6.12±0.46
YZ Cnc	DN	0.0868	13.17±0.02	0.22±0.03	0.12±0.03	3.34[a]	0.10	0.00[a]	5.78±0.24
AM Her	NL	0.1289	11.70±0.02	0.51±0.03	0.19±0.03	13.0[f]	0.09	0.00[j]	7.27±0.22
V603 Aql	N	0.1385	11.70±0.03	0.19±0.04	0.16±0.05	4.21[g]	0.38	0.08[h]	4.76±0.85
V1223 Sgr	NL	0.1402	12.81±0.02	0.07±0.04	0.10±0.04	1.95[e]	0.08	**0.15**[a]	**4.12±0.20**
RR Pic	N	0.1450	12.46±0.02	0.06±0.02	0.14±0.03	2.46[g]	0.32	0.02[h]	4.39±0.72
U Gem	DN	0.1769	11.65±0.02	0.58±0.03	0.24±0.03	9.96[a]	0.03	0.00[a]	6.64±0.09
SS Aur	DN	0.1828	12.70±0.02	0.43±0.03	0.27±0.03	5.99[a]	0.05	**0.03**[a]	**6.56±0.13**
IX Vel	NL	0.1939	9.12±0.03	0.14±0.04	0.15±0.03	10.38[g]	0.09	0.01[h]	4.20±0.23
V3885 Sgr	NL	0.2071	9.96±0.03	0.22±0.04	0.12±0.04	9.11[g]	0.19	0.02[h]	4.74±0.44
TV Col	NL	0.2286	13.20±0.03	0.37±0.03	0.14±0.04	2.70[d]	0.04	**0.05**[a]	**5.31±0.11**
RW Tri	NL	0.2319	11.94±0.02	0.36±0.03	0.12±0.03	2.93[c]	0.09	**0.26**[a]	**4.04±0.22**
RW Sex	NL	0.2451	10.32±0.03	0.18±0.04	0.08±0.03	3.46[g]	0.29	0.02[h]	3.00±0.66
AH Her	DN	0.2581	11.81±0.02	0.33±0.03	0.10±0.03	3[f]	0.40	0.03[h]	4.17±0.89
SS Cyg	DN	0.2751	8.52±0.02	0.16±0.03	0.06±0.03	6.06[a]	0.06	**0.04**[a]	**2.39±0.15**
Z Cam	DN	0.2898	11.57±0.03	0.53±0.03	0.19±0.04	8.9[f]	0.17	0.02[h]	6.31±0.40
RU Peg	DN	0.3746	11.07±0.02	0.44±0.03	0.16±0.03	3.55[a]	0.06	0.00[a]	3.82±0.15
AE Aqr	NL	0.4117	9.46±0.02	0.54±0.03	0.14±0.03	9.8[g]	0.24	0.00[h]	4.42±0.54
QU Car	NL	0.4540	10.97±0.02	0.12±0.03	0.14±0.03	1.64[g]	0.32	0.11[h]	2.04±0.72

a: Harrison et al. (2004), b: Beuermann et al. (2003a), c: McArthur et al. (1999), d: McArthur et al. (2001), e: Beuermann et al. (2003b), f: Thorstensen (2003), g: Duerbeck (1999), h: Bruch & Engel (1994), i: Schlegel et al. (1998), j: La Dous (1991)

M_J on the orbital period P_{orb}, and colours $(J-H)_0$ and $(H-K_s)_0$, we used a fit equation in the following form

$$M_J = a + b\ \log P_{orb}(day) + c\ (J-H)_0 + d\ (H-K)_0,$$

whose least square coefficients and their 1-σ errors are given in Table 2. The subscript '0' indicates de-reddened magnitudes. The M_J calibration that utilizes de-reddened colour indices $(J-H)_0$ and $(H-K_s)_0$ and the periods can be used to predict individual values within an error of about ± 0.22 mag. The correlation coefficient and standard deviation of the calibration

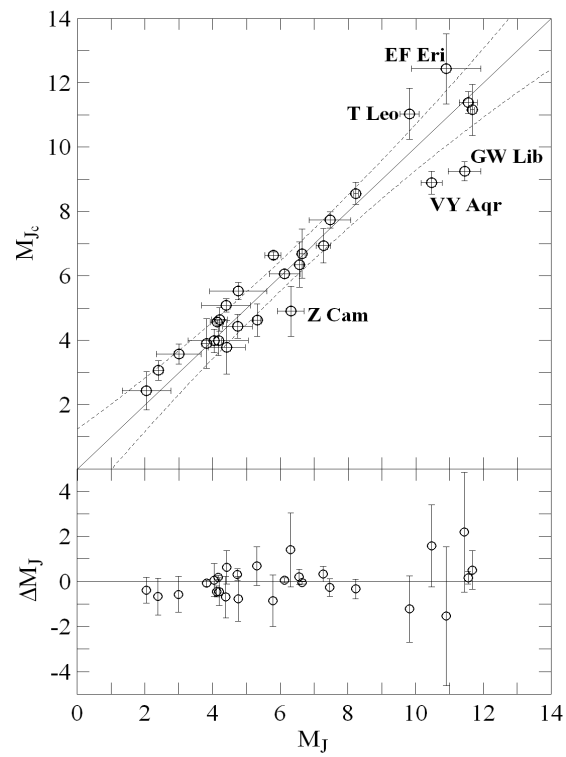

Fig. 1. A comparison of the absolute magnitudes (M_{Jc}) calculated from the PLCs relation with the estimated M_J absolute magnitudes in Table 1. Upper and lower confidence limits of 99% are shown with dotted lines. The bottom panel displays the residuals from the fit. The diagonal line represents the equal values. Largely scattered systems are shown.

Table 2
Coefficients of the calibration equation.

Coefficient	a	b	c	d
	-0.894	**-5.721**	**2.598**	**7.380**
σ	**±0.522**	**±0.705**	**±0.610**	**±1.711**

were estimated as $R = 0.96$ and $s = 0.88$, respectively. It should be emphasized that the calibration equation covers the ranges $0.032^d < P_{orb} \leq 0.454^d$, $-0.08 < (J-H)_0 \leq 1.54$, $-0.03 < (H-K_s)_0 \leq 0.56$ and $2.0 < M_J < 11.7$; It is based on trigonometric parallaxes with relative errors $(\sigma_\pi/\pi) \leq 0.4$. A comparison of the fit values of absolute magnitudes, M_{Jc}, calculated from this period-luminosity-colours (PLCs) relation with the observed M_J absolute magnitudes is shown in Figure 1.

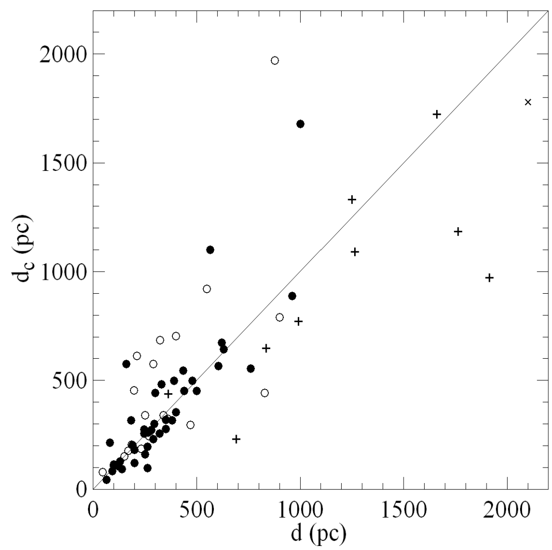

Fig. 2. A comparison of the distances (d_c) calculated using the absolute magnitudes (M_{Jc}) from the PLCs relation, with these distances (d) estimated from other methods. The diagonal line represents the equal values. The symbols $\bullet$, $\circ$ and $+$ denote dwarf novae, nova-like systems and novae respectively. The type of the cataclysmic variable J0813+4528 is unknown and it is shown by $\times$ in the figure.

3.1 Application to other cataclysmic variables

We collected the list of cataclysmic variables with $E(B-V)$ values from Bruch & Engel (1994). Then, we selected systems with orbital periods shorter than 12 hr from Downes et al.'s catalogue[2] (Downes et al. 2001) and with *2MASS* observations. Systems in the application limits of the PLCs relation (see, Section 3) are listed in Table 3. We also collected their distances, when available, from the literature. For example, Urban & Sion (2006) give distances of many dwarf novae estimated from the $M_v - P_{orb}$ relation. Most of the distances mentioned in Table 3 were taken from Urban & Sion (2006). $E(B-V)$ values and distances of EZ Del, LL Lyr, RY Ser, CH UMa and SDSS J081327.07+452833.0 were taken from Thorstensen et al. (2004), as well.

Distances of several systems were calculated by Sproats et al. (1996) using Bailey's method (Bailey 1981). However, their $E(B-V)$ values were not listed in Bruch & Engel (1994), **except for UV Per and AR And.** Among them, we selected the systems located above the Galactic latitude $\mid b \mid \geq 20^o$ and assumed $E(B-V)=0$ for them. This is a reasonable assumption since in these latitudes the interstellar absorption is very small. We have taken the distances from Sproats et al. (1996) calculated under the assumption that the percentage of the K-band light contributed by the secondary star is **50**, i.e. $K\%$=**50.**

2 http://archive.stsci.edu/prepds/cvcat/

Distances of V1500 Cyg and V533 Her in Table 3 were determined by the shell parallax method (Cohen 1985). For V1500 Cyg, we calculated the average distance of the nova collected from different sources. Selvelli (2004) calculated the $E(B-V)$ colour excesses and distances of some old novae from the UV spectra. We included these novae with orbital periods and *2MASS* observations in Table 3. Finally, Patterson (1984) listed distances of many CVs based on various methods, such as detection of the secondary, proper motion, $M_v - EW(H_\beta)$ relation, interstellar absorption, position in the Galaxy, etc. Note that none of the distances in Table 3 were determined by the trigonometric parallax method.

The absolute magnitudes (M_{Jc}) for the systems listed in Table 3 were calculated by using the calibration equation given above. The distances (d_c) were evaluated from the distance modulus formula with absolute magnitude M_{Jc} and interstellar absorption A_J. Figure 2 compares the distances obtained from the the PLCs relation with those collected from the literature.

4 Discussion

We have suggested an absolute magnitude calibration for CVs based on the trigonometric parallaxes and *2MASS* observations. The calibration equation covers a wide range of periods and colours. The mean error in the absolute magnitude M_J is 0.22. However, there is a considerable scatter for some systems.

Large deviations from the PLCs relation are seen mostly in faint systems. The source of the deviations can not be the colour excess $E(B-V)$, since the deviated systems are located in the middle and higher Galactic latitudes ($\mid b \mid \geq 27^o$) and they are relatively close objects. **Also, since they are relatively close objects, it is unlikely that they are due to parallax errors. It is therefore more likely that these deviations come from the intrinsic properties of the systems. Although for the systems GW Lib and EF Eri the magnitude flags in *2MASS* are (ABC) and (DBC), respectively, which indicates low-quality observations, the fact that the largest deviations come from systems with the faintest absolute magnitudes suggests that here the disc makes a more dominant contribution relative to the donor star than in systems with brighter donor stars. Indeed,** the nova-like system EF Eri has possibly a substellar secondary (Beuermann et al. 2000) and the deviation of this system from the PLCs relation can then be attributed to its very faint substellar component. Other deviated systems (GW Lib, T Leo, VY Aqr and Z Cam) are all dwarf novae. **Disc or donor activity** or a third component of the

Table 3
Absolute magnitudes M_{Jc} and distances d_c calculated from the PLCs relation found in this study. Columns 1–7 are as in Table 1. The letter d denotes distances collected from the literature. The type of the cataclysmic variable J0813+4528 is unknown.

Name	Type	$P_{orb}(d)$	J	$J-H$	$H-K_s$	$E(B-V)$	M_{Jc}	$d(pc)$	$d_c(pc)$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
DI UMa	DN	0.0546	15.53	0.27	0.14	0[a]	8.04	184[b]	316^{+5}_{-4}
AL Com	DN	0.0567	16.51	0.33	0.32	0[a]	9.43	264[b]	261^{+43}_{-51}
SW UMa	DN	0.0568	15.62	0.29	0.52	0[c]	10.81	140[d]	92^{+26}_{-35}
CP Pup	N	0.0614	14.34	0.10	0.21	0.25[c]	7.32	692[e]	229^{+3}_{-4}
V2051 Oph	DN	0.0624	14.33	0.46	0.34	0[c]	9.70	92[f]	84^{+18}_{-24}
V436 Cen	DN	0.0625	14.22	0.36	0.33	0.07[c]	9.23	263[g]	97^{+18}_{-21}
V347 Pav	NL	0.0626	16.20	0.68	0.54	0[a]	11.72	40-50[h]	79^{+29}_{-46}
OY Car	DN	0.0631	14.95	0.52	0.34	0[c]	9.81	100[i]	107^{+25}_{-32}
UV Per	DN	0.0649	16.47	0.74	0.30	0[c]	10.01	263[b]	196^{+50}_{-68}
SX LMi	DN	0.0672	15.71	0.15	0.17	0[a]	7.43	440[j]	453^{+14}_{-15}
IR Gem	DN	0.0684	15.22	0.34	0.34	0[c]	9.19	250[d]	160^{+32}_{-42}
HT Cas	DN	0.0736	14.70	0.48	0.38	0.03[c]	9.58	125[k]	104^{+27}_{-37}
VW Hyi	DN	0.0743	12.52	0.48	0.34	0.01[c]	9.28	65[d]	44^{+10}_{-14}
Z Cha	DN	0.0745	13.97	0.40	0.25	0[c]	8.45	130[i]	127^{+22}_{-25}
WX Hyi	DN	0.0748	13.48	0.24	0.28	0[c]	8.23	100[l]	113^{+17}_{-19}
BK Lyn	NL	0.0750	14.48	0.02	0.10	0[a]	6.32		428^{+18}_{-17}
RZ Leo	DN	0.0760	16.34	0.67	0.28	0[a]	9.30	246[b]	255^{+63}_{-84}
V503 Cyg	DN	0.0777	16.37	1.08	0.09	0[c]	8.91		310^{+69}_{-90}
DV UMa	DN	0.0859	16.89	1.03	0.07	0[a]	8.40	391[b]	499^{+106}_{-135}
HU Aqr	DN	0.0868	14.18	0.28	0.26	0[a]	7.83	231[b]	186^{+30}_{-37}
QS Tel	NL	0.0972	14.29	0.52	0.24	0[a]	8.06	170[m]	176^{+39}_{-51}
V592 Cas	NL	0.1151	12.29	0.04	0.07	0.25[n]	4.53	360[n]	323^{+19}_{-19}
V442 Oph	NL	0.1243	13.33	0.1	0.11	0.22[c]	4.90		443^{+5}_{-6}
AH Men	NL	0.1272	12.48	0.41	0.18	0[a]	6.60	150[o]	150^{+28}_{-34}
DN Gem	N	0.1278	15.43	0.20	-0.03	0.20[e]	4.08	1660[e]	1722^{+115}_{-108}
MV Lyr	NL	0.1323	15.86	0.52	0.16	0[c]	6.68	322[i]	686^{+140}_{-177}
BG CMi	NL	0.1347	14.55	0.27	0.14	0[c]	5.84		553^{+75}_{-86}
SW Sex	NL	0.1349	14.21	0.22	0.10	0[c]	5.41	290[p]	575^{+55}_{-61}
TT Ari	NL	0.1376	11.00	0.09	0.03	0.03[c]	4.42	185[i]	204^{+1}_{-1}
WX Ari	NL	0.1394	14.41	0.31	0.18	0[a]	6.12	198[b]	454^{+79}_{-95}
V1500 Cyg	N	0.1396	16.12	0.63	0.12	0.43[c]	5.56	1265[q,r,s]	1090^{+134}_{-152}
V1315 Aql	NL	0.1397	14.07	0.46	0.17	0.1[c]	6.22		356^{+65}_{-80}
V533 Her	N	0.147	14.71	0.05	0.02	0.03[c]	4.06	1250[t]	1332^{+13}_{-13}
AO Psc	NL	0.1496	13.46	0.15	0.22	0.02[u]	5.79	250[l]	339^{+56}_{-68}
AB Dra	DN	0.152	13.62	0.33	0.19	0.1[c]	5.80	400[d]	353^{+61}_{-74}
BZ Cam	NL	0.1536	13.36	0.21	0.12	0.05[v]	5.08	830[w]	443^{+49}_{-56}
IP Peg	DN	0.1582	12.60	0.63	0.25	0[c]	7.19	200[d]	121^{+36}_{-52}
LX Ser	NL	0.1584	13.93	0.16	0.12	0[c]	4.99	210[l]	613^{+70}_{-78}
VY For	NL	0.1586	15.59	0.59	0.13	0[a]	6.17		765^{+169}_{-216}
CY Lyr	DN	0.1591	13.63	0.26	0.15	0.18[c]	5.05	330[x]	483^{+59}_{-67}
CM Del	DN	0.162	13.43	0.19	0.11	0.09[c]	4.73		531^{+52}_{-56}
KT Per	DN	0.1627	13.31	0.49	0.20	0.18[c]	5.95	245[d]	275^{+58}_{-73}
AR And	DN	0.163	14.59	0.59	0.27	0.02[c]	7.08	380[b]	316^{+95}_{-135}
CN Ori	DN	0.1632	13.81	0.50	0.20	0[c]	6.41	295[d]	301^{+74}_{-100}
X Leo	DN	0.1644	14.29	0.40	0.29	0[c]	6.77	350[d]	318^{+89}_{-123}
VW Vul	DN	0.1687	13.52	0.25	0.11	0.15[c]	4.63	605[d]	566^{+58}_{-64}
UZ Ser	DN	0.173	14.03	0.48	0.35	0.33[d]	6.57	280[d]	271^{+75}_{-105}
GY Cnc	DN	0.1754	13.96	0.57	0.27	0[a]	6.92	320[y]	255^{+79}_{-114}
WW Cet	DN	0.1758	11.08	0.14	0.11	0.03[c]	4.53	190[d]	202^{+22}_{-24}
CW Mon	DN	0.1766	13.87	0.53	0.32	0.06[c]	7.02	290[i]	229^{+73}_{-106}

Table 3 — continued

Name	Type	$P_{orb}(d)$	J	$J-H$	$H-K_s$	$E(B-V)$	M_{Jc}	$d(pc)$	$d_c(pc)$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
TW Vir	DN	0.1827	13.35	0.27	0.14	0^{c}	5.07	500^{d}	452^{+77}_{-94}
DQ Her	N	0.1936	13.60	0.32	0.20	0.05^{e}	5.35	363^{e}	437^{+94}_{-119}
UX UMa	NL	0.1967	12.76	0.35	0.14	0.02^{c}	5.08	340^{l}	340^{+67}_{-83}
V345 Pav	NL	0.1981	12.15	0.39	0.09	0^{a}	4.80		295^{+52}_{-62}
BT Mon	N	0.3338	14.40	0.44	0.24	0.20^{e}	4.28	1914^{e}	972^{+286}_{-406}
FO Aqr	NL	0.2021	12.87	0.13	0.24	0^{c}	5.16		349^{+74}_{-93}
T Aur	N	0.2044	16.14	0.28	0.16	0.30^{e}	4.31	991^{e}	772^{+108}_{-127}
V446 Her	N	0.207	15.39	0.59	0.11	0.25^{e}	4.80	1762^{e}	1185^{+224}_{-277}
RX And	DN	0.2099	12.45	0.71	0.19	0.02^{c}	6.16	200^{d}	180^{+55}_{-78}
HR Del	N	0.2142	12.32	0.05	0.06	0.16^{e}	3.12	673^{e}	648^{+28}_{-28}
PQ Gem	NL	0.2164	13.49	0.29	0.20	0^{a}	5.18		459^{+108}_{-142}
HL CMa	DN	0.2168	11.64	0.19	0.22	0^{c}	4.99	80^{l}	214^{+47}_{-60}
AY Psc	DN	0.2173	14.52	0.50	0.02	0^{a}	4.31	565^{b}	1101^{+179}_{-214}
EZ Del	DN	0.2234	15.08	0.30	0.08	0.16^{z}	3.82	1000^{z}	1679^{+212}_{-243}
V347 Pup	NL	0.2319	13.13	0.65	0.19	0.05^{aa}	5.73	470^{aa}	296^{+89}_{-126}
DO Leo	DN	0.2345	15.93	0.73	-0.02	0^{a}	4.45	878^{b}	1971^{+397}_{-496}
TX Col	NL	0.2383	13.63	0.26	0.20	0.05^{c}	4.73		591^{+135}_{-175}
AH Eri	DN	0.2391	15.92	0.58	0.40	0^{a}	7.12	160^{b}	576^{+232}_{-390}
LL Lyr	DN	0.2491	15.42	0.53	0.25	0.06^{z}	5.63	960^{z}	887^{+277}_{-402}
XY Ari	NL	0.2527	16.14	1.88	0.90	3.7^{bb}	5.93	270^{bb}	243^{+82}_{-123}
TZ Per	DN	0.2629	13.09	0.58	0.11	0.27^{c}	4.17	435^{d}	545^{+116}_{-147}
BV Pup	DN	0.265	13.34	0.45	0.10	0^{c}	4.30	630^{d}	642^{+145}_{-188}
TT Crt	DN	0.2684	13.87	0.48	0.21	0^{d}	5.16	500^{d}	554^{+165}_{-235}
V426 Oph	DN	0.2853	11.00	0.50	0.17	0.08^{c}	4.58	202^{cc}	186^{+51}_{-69}
J0813+4528	CV	0.289	15.94	0.68	0.11	0.05^{z}	4.64	2100^{z}	1779^{+499}_{-695}
EM Cyg	DN	0.2909	11.74	0.40	0.18	0.03^{c}	4.50	350^{d}	277^{+75}_{-102}
AC Cnc	NL	0.3005	13.08	0.38	0.10	0^{c}	3.84	400^{l}	704^{+161}_{-208}
RY Ser	DN	0.3009	13.70	0.63	0.18	0.39^{z}	4.21	620^{z}	673^{+174}_{-235}
V363 Aur	NL	0.3212	13.30	0.33	0.16	0.13^{c}	3.69	900^{dd}	790^{+187}_{-245}
V1309 Ori	NL	0.3326	14.22	0.56	0.15	0^{a}	4.40	550^{ee}	920^{+279}_{-399}
CH UMa	DN	0.3432	12.71	0.50	0.17	0.06^{z}	4.17	480^{z}	498^{+146}_{-208}
SY Cnc	DN	0.38	11.27	0.22	0.13	0^{c}	3.04	300^{l}	443^{+104}_{-137}
Q Cyg	N	0.4202	13.54	0.29	0.14	0.44^{c}	2.12	2188^{e}	1610^{+306}_{-376}

a: assumed value (see text), b: Sproats et al. (1996), c: Bruch & Engel (1994), d: Urban & Sion (2006), e: Selvelli (2004), f: Saito & Baptista (2006) g: Nadalin & Sion (2001) h: Ramsay et al. (2004), i: Verbunt et al. (1997) j: Wagner et al. (1998) k: Wood et al. (1992) l: Patterson (1984), m: Gerke et al. (2006), n: Taylor et al. (1998), o: Gaensicke & Koester (1999), p: Groot et al. (2001), q: Esenoglu (1997), r: Cohen (1985), s: Duerbeck (1981), t: Gill & O'Brien (2000), u: Hellier & van Zyl (2005), v: Prinja et al. (2000), w: Ringwald & Naylor (1998), x: Thorstensen & Taylor (1998), y: Gaensicke et al. (2000), z: Thorstensen et al. (2004), aa: Thoroughgood et al. (2005), bb: Littlefair et. al. (2001), cc: Hessman (1988), dd: Warner (1995), ee: Staude et al. (2001)

binary system can affect the magnitude of the system. We used AAVSO's Light Curve Generator [3] to find the activity stage of these systems during the *2MASS* observations. Unfortunately, only Z Cam has enough visual observations to conclude that its activity stage. We found that this system was at the beginning of the decline from an outburst during the *2MASS* observations.

As for the non or **less-deviating** dwarf novae from the PLCs relation, only SU UMa was found in a superoutburst maximum from the AAVSO's Light Curve Generator. Other dwarf novae were either in quiescence (WZ Sge, EX Hya, V893 Sco, YZ Cnc, U Gem, SS Aur, RU Peg) or in the decline branch from an outburst (AH Her and SS Cyg) like Z Cam during the *2MASS* obser-

[3] http://www.aavso.org/data/lcg/

vations. These systems are located in or very near the 99% confidence limit without regarding their activity stage. So, it is possible to say that activity stage does not affect the location of a CV in the PLCs relation. However, **it seems** that finding considerable deviations from the PLCs relation mostly for some dwarf novae **is not** a coincidence **(Interestingly note that the nova-like star GP Com, in which a CO white dwarf is acreeting from a helium degenerate (Morales-Rueda et al. 2003), obeys the relation very well).**

We compared the distances obtained from the PLCs relation with those found by various other methods in Figure 2. Although Figure 2 shows that the distances found from the PLCs relation are generally somewhat **smaller** than those found by other methods, **for the nova-like systems** the PLCs relation yields distances longer than other methods. The distance inferred from the trigonometric parallax of HR Del is very different than found from its shell parallax (760 pc, Duerbeck 1999). This is why we did not include this system in our data sample listed in Table 1. Its distance found from the PLCs relation is, bf however, much closer to that obtained from the shell parallax.

In view of the above results, we suggest that the PLCs relation can be a useful statistical tool to calculate the distances of CVs from their *2MASS* observations since the PLCs relation **has been calibrated** with the most reliable distance estimation method (trigonometric parallax). Distances calculated from the PLCs relation can give clues for astrometric observations of these systems, as well. Finally, it should be stated that future astrometric observations of CVs such as *GAIA* and *SIM* missions, will refine the PLCs relation.

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